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# THE VIRTUAL 3D CITY MODEL OF BERLIN - MANAGING, INTEGRATING AND COMMUNICATING COMPLEX URBAN INFORMATION

**Jürgen Döllner**[1]
**Thomas H. Kolbe**[2]
**Falko Liecke**[3]
**Takis Sgouros**[4]
**Karin Teichmann**[5]

[1]Hasso-Plattner-Institut at the University of Potsdam
[2]Institute of Cartography and Geoinformation at the University of Bonn
[3]Senate Department of Economics, Labour and Women's Issues, Berlin
[4]Senate Department of Urban Development, Berlin
[5]Berlin Partner GmbH, Berlin
Germany

## ABSTRACT

This contribution reports on concepts, implementation, and experience of the Berlin virtual 3D city model, a project that has developed a system for integrating, managing, integrating, presenting, and distributing complex urban geoinformation. It has been initiated by the Senate Department of Economics and the Senate Department of Urban Development in order to extend Berlin's geodata infrastructure by a novel, flexible, and state-of-the-art geoinformation technology. As first applications, the virtual 3D city model forms core part of the investor information system hosted at the Berlin Business Location Center, and it represents the basis for ongoing projects in city planning at the architecture working group of the Senate Department of Urban Development.

## INTRODUCTION

In 2003, the Senate Departments of Economics and Urban Development of Berlin started the development of concepts and an implementation for the official virtual 3D city model. In the first step, key requirements were identified that shape the city model system:

- Support for integrating heterogeneous sources of administrative geoinformation under the umbrella of the virtual 3D city model.
- Acquisition of 3D geodata for representative areas of the city and evaluation of the applied geodata capturing technologies.
- Adaptation and redefinition of administrative workflows to ensure model correctness in terms of the official cadastral database and to ensure sustainability.
- Interactive systems for presenting and communicating contents of the virtual 3D city model to various target users and application areas.
- Development and test of new distributing technologies and business models for the dissemination of city model contents.

## DEVELOPMENT DIRECTIONS OF VIRTUAL CITY MODELS

*Virtual 3D city models* represent urban spatial data and geo-referenced data under a common metaphor, the virtual city. Their fundamental components include digital terrain models (DTMs), building models, street-space models, and green-space models. In a sense, virtual 3D city models can be considered to be *3D geovirtual environments* (GeoVEs) that serve as the interactive interface between city model contents and users. With geovirtual environments, we can present contents to users, explore unknown geoinformation, analyze geoinformation, and manage the storage of geoinformation. Virtual 3D city models, therefore, constitute a major concept in 3D geoinformation systems (3D GIS). For a general introduction to geovisualization we refer to *Dykes et al. (2005)*.

### Towards Automation

One main barrier in developing virtual 3D city models represents the time and cost inefficient creation of model data (*Ribarsky & Wasilewski 2002*). Manual geometric modeling can be accepted in small-scale virtual 3D city models but fails if virtual 3D city models are required for large urban areas or if they should be managed in the long run. Therefore, virtual 3D city models need to be based on automatic and semiautomatic acquisition methods wherever possible. Recent advances in remote sensing and data processing are about to overcome this limitation providing a high degree of automated capturing and processing of geodata such as for detailed building geometry including roofs as well as for vegetation.

### Towards Integration

Weak integration of maintenance and update processes in administrative workflows represents another bottleneck in developing virtual 3D city models. If the model generation and updating processes are not seamlessly integrated into administrative workflows, then the model's quality lacks with respect to its legal correctness, completeness, and up-to-dateness. Without seamless integration, virtual 3D city models tend to remain isolated and may become rapidly obsolete artifacts.

### Towards Semantics Besides Geometry and Graphics

In recent years, most virtual 3D city models have been realized as purely graphical or geometrical models, sometimes represented by virtual "3D worlds". These models focus on presentational tasks and, therefore, aim at a photorealistic resembling of visual urban objects – the ultimate goal was verisimilarity, that is, a virtual 3D city model that comes as close as possible to its physical counterpart, in particular, to its visual appearance.

However, if semantic and topological aspects are neglected, these models can almost only be used for visualization purposes but not for thematic queries, analysis tasks, or spatial data mining. An increasing number of applications and systems incorporate virtual 3D city models as essential system components in the last years. Examples are IT solutions in the fields of telecommunication, disaster management, homeland security, facility management, real estate portals, logistics, as well as for entertainment and educational purposes. In general, these applications and system provide specific functionality on top of the virtual 3D city model, e.g., the PegaPlan-3D network planning system of T-Mobile Germany visualizes and manipulates the configuration of radio network servers and antenna systems. Therefore, virtual 3D city models should be understood as the "3D components" of general-purpose geodata infrastructures. The official 3D city model of Berlin contributes to these goals.

## Towards Standardization of Virtual City Models

Since the limited reusability of models inhibits the broader use of 3D city models, a more general modeling approach had to be taken in order to satisfy the model requirements of the various application fields.

With CityGML, a first open data model and XML-based format for the storage and exchange of virtual 3D city models becomes available (*Kolbe et al. 2005*). It is implemented as an application schema for the Geography Markup Language 3 (GML3), the extendible international standard for spatial data exchange issued by the Open Geospatial Consortium (OGC) and the ISO TC211. CityGML is intended to become an open standard and therefore can be used free of charge.

CityGML does not only represents the graphical appearance of city models but especially takes care of the representation of the semantic and thematic properties, taxonomies and aggregations of

- digital terrain models (DTMs),
- sites (including buildings, bridges, tunnels, …),
- vegetation,
- water bodies,
- transportation facilities, and
- city furniture (including traffic lights, traffic signs, billboards, …).

The underlying model differentiates five consecutive levels of detail (LOD), where objects become more detailed with increasing LOD regarding both geometry and thematic differentiation. CityGML files can - but don't have to - contain multiple representations for each object in different LOD simultaneously.

## COMPLEX URBAN INFORMATION SPACES

*Complex urban information spaces* refer to virtual 3D city models having thematic and application-specific georeferenced data that is jointly presented and related to the objects of virtual 3D city models. For example, a real-estate portal can visualize vacancy, year-of-construction, and average monthly rent of buildings by mapping the data onto façade color, façade texture, and roof colors used as visual variables. In this case, virtual 3D city models serve as urban data mining tools.

## SYSTEM ARCHITECTURE OF THE BERLIN MODEL

The virtual 3D city model of Berlin acts as an integration platform for 2D and 3D geodata and georeferenced data instead of being only a 3D geometry or graphics model. Its system architecture is modeled by a collection of interrelated subsystems. The architecture ensures that individual subsystems can grow independently and communicate through explicitly defined data interfaces.

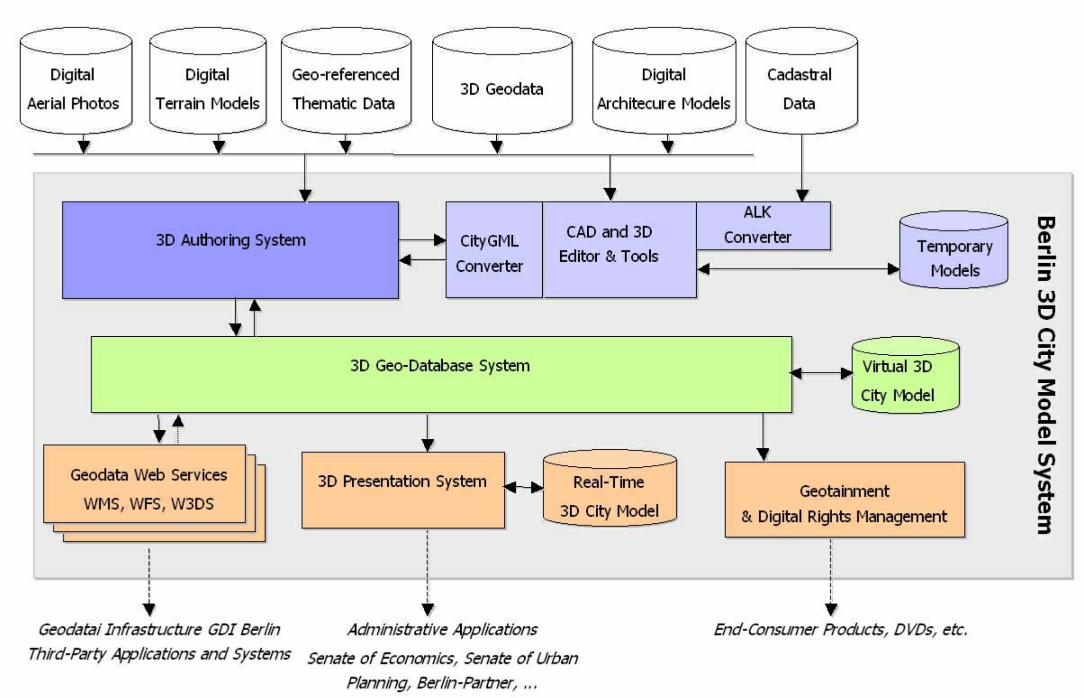


*Fig. 1: The system architecture of the Virtual 3D City Model of Berlin.*

Its main objectives encompass the *management* of the underlying geoinformation and its integration into administrative workflows by a central 3D geo-database; the on-demand, on-the-fly *integration* of georeferenced thematic data with (parts of) the virtual 3D city model, and the dissemination and *distribution* of the virtual 3D city models through a number of digital media such as Internet, imagery, video, and DVD.

The overall architecture of the system is outlined in Fig. 1 and is constituted by the following principal subsystems:

- *3D Authoring System*: It is responsible for creating, editing, and versioning of the virtual 3D city models and its components, e.g., importing, exporting, grouping, and annotating buildings, vegetation plans, landscape plans, etc. Technically, it provides an interactive access to the 3D geo-database. In our project, the 3D authoring system LandXplorer Studio (*3D Geo 2006*) has been incorporated and extended by a CityGML interface.
- *3D Geo-Database System*: The database for storing and managing virtual 3D city models is based on the logical structure of CityGML. Therefore, the database also supports semantic and thematic properties, taxonomies, and aggregations. Its principal object, the city object, represents geo-referenced, geometric entities. Specialized classes of city objects include buildings, green-spaces, street-spaces, transportation networks, water bodies, vegetations, and plants.
- *3D Editor System*: The editor is responsible for creating, editing, and geometric modeling of specific 3D objects such as architectural building models or 3D landmark models. For example, in the Berlin project, we apply the ArchiCAD editor for architectural models, whereas 3D Studio Max is used as general-purpose 3D modeler. This approach allows us to support a broad spectrum of digital 3D contents and to fulfill specific editing needs of applications and users.
- *3D Presentation System*: The presentation system provides real-time visualization of and interaction with the virtual 3D city model. In contrast to the 3D authoring system, the presentation system is targeted at specific media (e.g., Internet, DVD) and specific user groups (e.g., general public, experts, and politicians). In the Berlin project, one

presentation system has been developed for the Business Location Center, which supports companies considering relocating to Berlin-Brandenburg by presenting all key decision-making factors within the virtual 3D city model. In a showroom, a large-screen projection gives impressive presentations tailored to the specific needs of clients.
- *Geospatial Digital Rights Management System*: As a complementary functionality, a geospatial digital rights system can be applied for gathering, enclosing, compressing, encrypting, and controlling digital contents of the virtual 3D city model on different media such as DVDs.

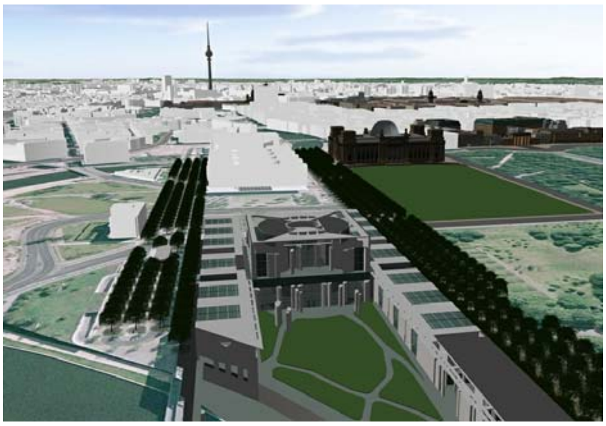

*Fig. 2: Block models and architectural models integrated into a single view.*

## GEODATA UNDERLYING THE VIRTUAL 3D CITY MODEL

In the virtual 3D city model of Berlin, the following geodata sources form part of the system:
- *Cadastral Data*: The cadastral database delivers the official footprints of buildings and land parcels as well as ownership and address information. It provides the essential legal information about land parcels and buildings.
- *Digital Terrain Model*: The available grid-based DTMs vary in resolution and extension. For the whole urban area of approx. 900 $km^2$, a coarse DTM of 20 m resolution builds the framework; a higher-resolution DTM is used for the core part of the virtual 3D city model. In areas of special interest, an explicit 3D model of the terrain surface structure replaces the grid-based DTMs.
- *Aerial Photography*: A collection of digital aerial photography is linked to the virtual 3D city model. They can be projected on top of the digital terrain model.
- *Building Models*: For more than 250 $km^2$ of the city, 3D building geometry has been captured and processed by laser-scanning and photogrammetry-based methods. The buildings are represented at various levels of detail, including block-models (LOD-1), geometry-models (LOD-2), architectural models (LOD-3), and detailed indoor models (LOD-4). Fig. 2 shows a configuration integrating LOD-1 and LOD-3 building models.
- *Versions and Variants*: A given city object can be updated and, therefore, have multiple versions. In a similar way, a given area can contain different variants of city object collections.

Apart from the geodata listed above, the virtual 3D city model can be enhanced by classical georeferenced 2D raster-data sources (e.g., rasterized 2D maps) and vector-data sources (e.g., transportation networks).

## VISUALIZATION OF URBAN INFORMATION

Virtual 3D city models serve as generic tools for an increasing number of application areas in administration and industry that demand for visualizing geoinformation. For that reason, the requirements made on the visualization techniques vary. In the Berlin project, we explicitly address several visualization techniques.

### Photorealistic Visualization

In the context of tourism, entertainment, or public participation a high degree of photorealism is required (Fig. 3). For instance, if the aim is to give a realistic impression of a planned environment, the quality of a 3D visualization is directly related to the similarity between the virtual city model and the actual result after implementation of the planning.

To enable real-time rendering of large-scale 3D city models, their geometric complexity has to be reduced in order to guarantee high and constant frame rates. For virtual environments, geometry or texture related optimization and multiresolution algorithms and data structures can be applied to achieve real-time rendering even for complex virtual 3D city models (e.g., *Buchholz & Döllner 2005b, Willmott et al. 2001*).

*Fig. 3: Example of a photorealistic visualization (Source:"Berlin-3D"from RSS GmbH, Potsdam/München, DRL Berlin-Adlershof, and 3D Geo GmbH, Potsdam).*

### Information Visualization

For applications in information visualization and data mining, photographics details of buildings are not of primary interest. Instead, the 3D representation of a city model serves as a medium to convey spatial-related thematic information in a comprehensive way (*Müller & Schumann 2002*). In the context of urban planning, e.g., thematic building information such as vacancy, ownership, or year of construction has to be considered (*Buchholz & Döllner 2005a*). Here, an abstracted, simplified visual design is required that typically encodes planning status, planning variants, or related planning information (Fig. 4).

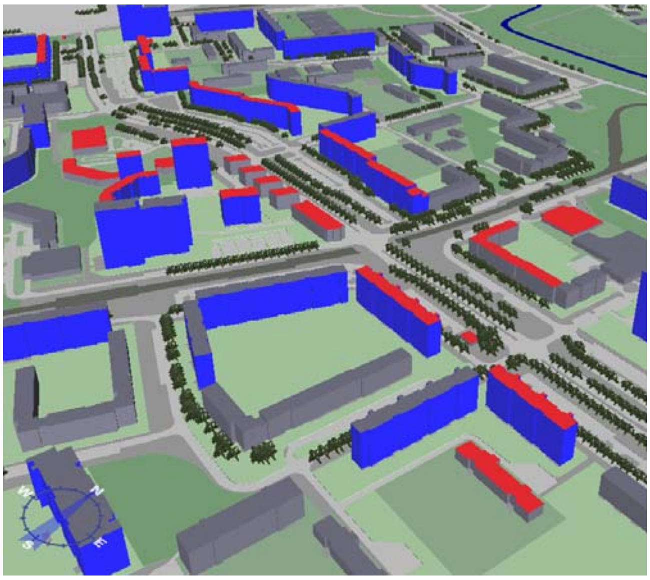

*Fig. 4: Example of thematic information visualization.*

## RESULTS AND GAINED EXPERIENCE

After completing the first phase of the virtual city model of Berlin in 2005, we can conclude and summarize the gained experience with respect to data acquisition and the system architecture.

### Data Acqusition

Two different acquisition and geodata processing techniques for 3D geodata were deployed, a photogrammetric analysis of high-resolution, true orthophotos captured with the high-resolution stereoscopic camera (HRSC) and an analysis of LIDAR data based on laser scanning. For both methods, the target region represented the city center of Berlin (approx. 200 km$^2$). For a general overview of 3D geodata acquisition see (*Förstner 1999*).

The HRSC technique (developed by the German Aero Space Center DLR, Berlin Adlershof) delivered high-quality colors and true-orthographic aerial imagery. In particular, the resolution of approx. 15 cm allows the user explore even small details. Furthermore, the imagery could be used to texture the roofs of building models with the true image of each individual building. The automatic extraction of 3D building models based on given footprints derived from the cadaster database lead to precise results. In contrast, the DTM derived from HRSC data shows equally spread errors that prevented the actual deployment of this DTM in our project. The laser-scan data was processed for both DTM and buildings. In both cases – due to the nature of the data and corresponding capturing technology – show precise and high-quality results.

The HRSC method did not only use the footprints of buildings but also floor-separating lines (i.e., lines that split building parts having a different number of floors). The resulting enhanced LOD-1 models are beneficial because their visualization quality is much higher than regular block models because these buildings reflect an important perceptive and cognitive aspect of buildings models, namely differentiated building parts (Fig. 5).

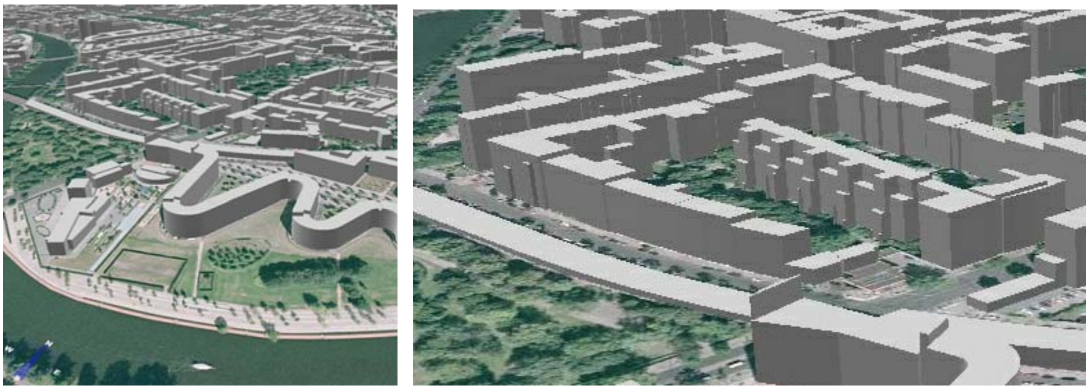

*Fig. 5: Example of enhanced block models with differentiated heights in individual building parts.*

LOD-2 buildings, which explicitly model roof type and geometry, further enhance the model in selected areas of high importance. Since most buildings in the city center tend to have a near-flat roof, detailed roof geometry only provide a gradual progress in the downtown area for most buildings, in particular, if compared to the enhanced LOD-1 buildings. For both, LOD-1 and LOD-2 building models, the presentation system is able to automatically project aerial photography on top of the roofs. This way, the appearance of a roof (including its shading) can be provided with high visual detail (Fig. 6).

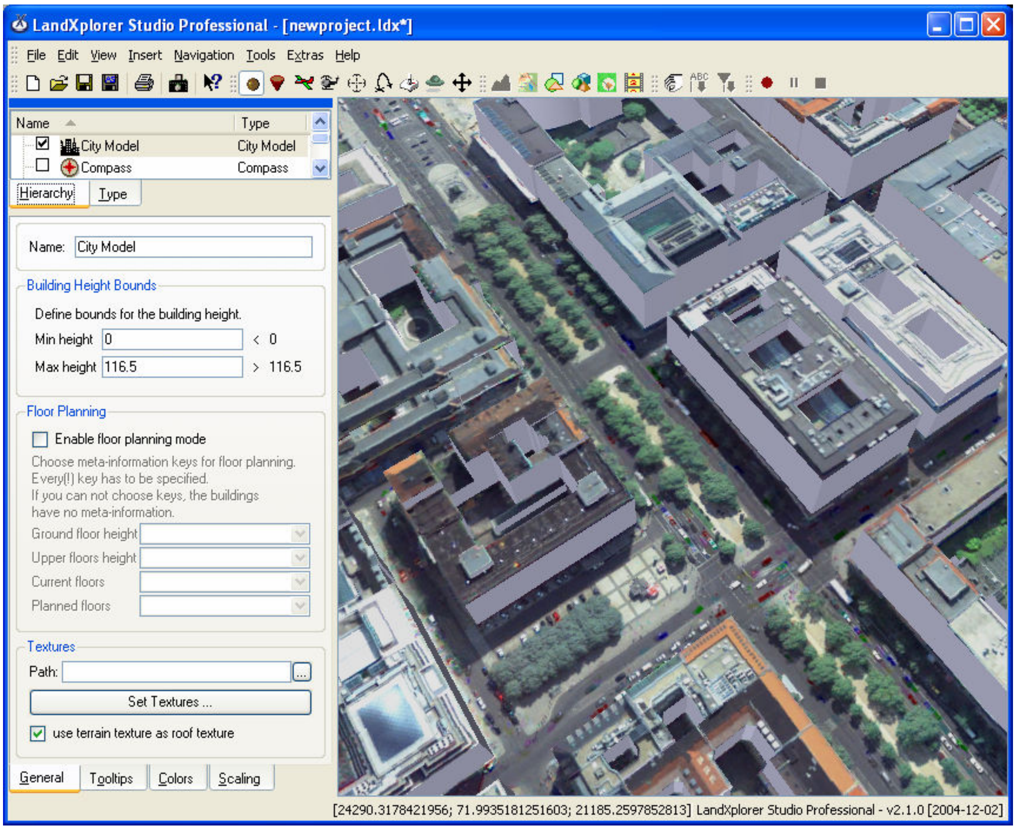


*Fig. 6: User interface of the authoring tool, showing block models with roof textures taken from aerial photography.*

From the predecessor virtual 3D city model, we could convert existing LOD-3 and LOD-4 buildings, mostly architectural models of landmark buildings, into the new system. For this, the originally VRML-encoded models have been converted in X3D models or 3DS models.

On the one hand, X3D (the successor of VRML) has an XML-based syntax, which simplifies the implementation of the authoring and presentation system. On the other hand, for 3DS models professional 3D modeling tools are available, which simplifies the change management and offers high compatibility.

**System Architecture and Subsystems**

We decided to separate the database for 3D geoinformation from all other subsystems because its design and implementation should be kept independent from authoring, editing, and presentation issues. The database also allows applications and systems to access the contents of the virtual 3D city model without having to use other subsystems. A privileged access is given to the 3D authoring system that performs both read and write operations on the database. The database schemata generally follow the data model proposed by CityGML to ensure a high degree of compatibility. As a pragmatic decision, the database keeps its own extracted and transformed cadastral information to avoid organizational and technical interferences.

The presentation system, LandXplorer, has been designed to fulfill the specific requirements of the Business Location Center and its core task, the interactive presentation of city model contents during investor meetings. For this reasons, special attention has been paid to visual bookmarks, which facilitate the rapid navigation through the model and allow users to immediately design short movie clips. In addition, there is functionality for the ad-hoc creation of contents (*Döllner et al. 2005*), e.g., potential building plans, points-of-interest, web links, etc. Furthermore, the presentation system offers functions to export selected parts of the model to different media, e.g., large-scale images, panoramic images, or movies. The authoring system is based on LandXplorer Studio as well.

**Distribution**

In the next stage of the project, techniques for accessing the virtual city models from general third-part systems will be investigate. In its current version, the system concentrates on exchanging contents by CityGML within the internal workflows (i.e., between authoring, presentation, and editor systems). The available concepts and standards of web services are generally directed towards 2D geoinformation – for 3D geoinformation there is still no broad set of services that would allow to fully access the contents of a virtual 3D city model. Part of this limitation is due to digital rights issues and due to bandwidth limits. For real-time visualization applications, a fast and direct access to optimized, preprocessed content data is indispensable. This can hardly be achieved by data exchange services.

As one way of distribution, the project released an interactive DVD product that contains part of the virtual 3D city model and a corresponding real-time visualization application (the viewer). The DVD compactly disseminates selected parts of the virtual 3D city model by an intuitive user-interface and provides a certain degree of digital rights management.

This DVD product is based on geotainment technology (*3D Geo 2006*), which aims at encapsulating 3D geovirtual environments together with their underlying geodata in self-contained, read-to-use, and secured mass-market applications. The content data on the DVD has been compressed, linearized, and encrypted such that the original data cannot be extracted but directly processed by the real-time rendering engine.

## Open Problems

As open problems, the available distribution technology as well as a corresponding business model are still insuffient. We expect that 3D web-services will partially solve this situation. In addition, we have observed that the current cadastral data requires extra processing steps and a differential comparison to previous versions. An object-based data exchange and an incremental update service would resolve that obstacle and further smoothen the integration into administrative workflows.

## CONCLUSIONS

This contribution has presented the concepts and system architecture of the virtual 3D city model of Berlin, an interactive system for the management, integration, presentation, and distribution of complex urban geoinformation based on a uniform communication metaphor, the virtual city.

In our experience, the decoupling of the system's functionality into subsystems for content authoring, editing, storing, and presentation leads to an open, extendible, and transparent geoinformation system. As a fundamental concept, CityGML as well as a number of identified standard GIS formats provide a high degree of interoperability. Innovative visualization techniques beyond photorealism, such as information visualization and illustrative visualization, allow us to address new application areas and improve the quality and usability of the information display. As an essential component of a modern geodata infrastructure, the virtual 3D city model of Berlin seamlessly integrates key information of the cadastral database but keeps the 3D geo-database separated and, therefore, operation and updating processes independent.

In our current activities, web-services for the model's contents are under development to further extend the ways the city model can be accessed by third-party applications and systems by industry, administration, and sciences. Furthermore, techniques for the automated mapping of 2D landscape plans and architectural plans to virtual 3D city models based on a heuristic-algorithmic approach will be incorporated.

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## CVs of the Authors

Jürgen Döllner studied mathematics and computer science, got his Ph.D. on object-oriented 3D modeling and visualization, and his venia legendi in computer science. In 2001, he has become head of the computer graphics division at the Hasso-Plattner-Institute of the University of Potsdam, Germany. His fields of research include computer graphics, visualization as well as geovisualization and geoinformatics.

Thomas H. Kolbe is senior researcher und lecturer at the Institute for Cartography and Geoinformation at the University of Bonn, Germany. His research interests cover 3D GIS, 3D city models, spatial data infrastructures, computer vision, and information theory. He is chairman of the Special Interest Group 3D (SIG 3D) of the initiative Geodata Infrastructure North Rhine-Westphalia (GDI NRW), being the originator of OGC's Web 3D Service and CityGML.

Falko Liecke is working at the Senate Department of Economics, Labour, and Women's Issues. His interests include geodata infrastructures and innovative platforms for administrative information. He initiated the virtual city model project of Berlin.

Takis Sgouros studied architecture and is leading the CAD development at the architecture working group (Architekturwerkstatt) of the Senate Department of Urban Development, Berlin. His initiated the first virtual 3D city model of Berlin and responsible for the creation and management of digital plans and city models.

Karin Teichmann is working for Berlin Partner GmbH (formerly Berlin Business Development Corporation) since 2001. In 2004 she became head of the Business Location Center, a multimedia portal supporting companies considering to relocate to Berlin-Brandenburg by presenting them the key decision-making factors.

## Co-ordinates

Prof. Dr. Jürgen Döllner

| | | |
|---|---|---|
| Institution | : | Hasso-Plattner-Institute at the University of Potsdam |
| Address | : | Prof.-Dr.-Helmert-Str. 2-3 |
| Postal Code | : | 14482 Potsdam |
| Country | : | Germany |
| Telephone number | : | ++49 331 5509 170 |
| Fax number | : | ++49 331 5509 179 |
| E-mail address | : | doellner@hpi.uni-potsdam.de |
| Website | : | www.hpi.uni-potsdam.de/3d |

Dr. Thomas H. Kolbe

| | | |
|---|---|---|
| Institution | : | Institute of Cartography and Geoinformatics |
| Address | : | Meckenheimer Allee 172 |
| Postal Code | : | 53123 Bonn |

Country : Germany
Telephone number : ++49 228 731760
Fax number : ++49 228 731753
E-mail address : kolbe@ikg.uni-bonn.de
Website : www.ikg.uni-bonn.de/kolbe

Falko Liecke
Institution : Senate Department of Economics, Labour, and Women's Issues
Address : Martin-Luther-Straße 105
Postal Code : 10820 Berlin
Country : Germany
Telephone number : ++49 30 9013 7538
Fax number : ++49 30 9013 8050
E-mail address : falko.liecke@senwaf.verwalt-berlin.de
Website : www.berlin.de/wirtschaftssenat

Takis Sgouros
Institution : Senate Department of Urban Development, Architekturwerkstatt
Address : Behrenstr. 42
Postal Code : 10117 Berlin
Country : Germany
Telephone number : ++49 30 9020 5043
Fax number : ++49 30 9028 3211
E-mail address : takis.sgouros@senstadt.verwalt-berlin.de
Website : www.stadtentwicklung.berlin.de

Karin Teichmann
Institution : Berlin Partner GmbH
Address : Fasanenstrasse 85
Postal Code : 10623 Berlin
Country : Germany
Telephone number : ++49 30 399 80 - 256
Fax number : ++49 30 399 80 - 239
E-mail address : Karin.Teichmann@berlin-partner.de
Website : www.businesslocationcenter.de
www.berlin-partner.de